ecoinvent: Materials and Agriculture

Manufacturing and Disposal of Building Materials and Inventorying Infrastructure in ecoinvent

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Abstract

Goal, Scope and Background. The present paper describes the goal and scope of building material inventories in the ecoinvent database and gives an overview of its content. The ecoinvent database provides generic life cycle inventories for building material production and related processing. They can be used as background data for different LCA applications. Their geographical and temporal scope is Switzerland or Europe and the year 2000.

Methods. Data is inventoried as unit processes. Consistency throughout different sources is heeded by systematically estimating missing data. Infrastructure is consequently considered. Different disposal options are modelled.

Results and Conclusion. The ecoinvent data provide a harmonised basis for different kinds of building materials. Even though not all datasets could be established on the same quality level, the results generally are believed to be comparable. Since data are generic, they are, however, not suitable to directly compare specific products. Disposal is relevant for the environmental burdens of uses of building materials. Complete life cycles have to be assessed. For this purpose, cumulative energy demand (CED) is not a suitable indicator.

Recommendation and Perspective. In future versions of ecoinvent, data quality could be further improved. The database should be extended to include further building materials from secondary materials. To do so, the methodological treatment of secondary materials needs special attention.

Keywords: Building materials; cumulative energy demand (CED); disposal; ecoinvent; gypsum building products; infrastructure; Life cycle Inventory (LCI); Switzerland

Introduction

Life cycle inventory data for the production and processing of a great number of building materials were developed and harmonised within the framework of the ecoinvent 2000 project (Frischknecht et al. 2004c). According to the broad and intensive use of the building material data in Frischknecht et al. (1996) all over Europe, these inventories were given high priority.

The present paper describes the goal and scope of building material inventories in the ecoinvent database and gives an overview of its content. Furthermore, some important modelling principles of inventorying building materials are discussed. The focus in this part is on data structure and boundaries, on inventorying building material disposal and on inventorying infrastructure, especially land-use. The aspects are shown in a case study of the production and disposal of gypsum fibre board.

1 Goal and Scope of Building Materials and their Disposal in ecoinvent

For general information on goal and scope of the ecoinvent database refer to Frischknecht et al. (2004a). The goal of the building material inventories in ecoinvent is to provide generic background data to be used in LCA of products (e.g. buildings) and processes. Ecoinvent datasets on building materials are not meant to be used to directly compare similar products of the same function (e.g. different insulation materials). Like all ecoinvent data, the building material inventories relate to the common technology mix for the year 2000 and to Switzerland and Europe.

Ecological assessments of buildings, construction and building materials are often focussed on the production and use phase. Disposal is often disregarded. In a complete Life Cycle Assessment, all processes should be considered. In ecoinvent, the disposal of common building materials is inventoried (part V of Doka 2003). This data is fit to complement inventory data for the production of materials. These inventories are designated to be used for the assessment of buildings in the planning stage. Disposal options are heavily influenced by type of construction, procedures in the utilisation of the material and site-specific disposal logistics. Hence, the disposal of building materials cannot be assessed with regard to a specific material alone.

1.1 Building materials inventoried

The ecoinvent database contains about 125 specific building materials and processes (Kellenberger et al. 2004). In addition, there are inventories for metals, plastics and wooden materials which are reported separately (Althaus et al. 2004, Hischier 2004 and Werner et al. 2003). A short summary illustrates the content and background:

Sand/gravel/clinker/cement/concrete: Most of these data are mainly based on a study made by EMPA in the year 2000 (Künniger et al. 2001). The comprehensive data cover the Swiss production.

Lime products: Most data of the different limestone-based products (limestone, quicklime, hydrated lime) are provided by the only company in Switzerland producing hydrated lime (Kalkfabrik Netstal). The detailed data refer to the year 2000.

Brick/tile/refractory bricks/ceramics/sand-lime brick: The data used for the brick and roof tile inventories are from a study which covers twelve factories in Germany, Austria and Switzerland. The data of refractory bricks are mainly based on personal communication. Data for the production of ceramic tiles and sanitary ceramic products are taken from an LCA study of tile production in Italy and from an environmental report of one producer in Germany.

Glass products: The data for uncoated flat glass mainly refer to IPPC (2001) and assumptions which reduced the data quality. The data for the coating process are based on an environmental report from a German company and refer to the year 2000.

Insulation materials: The database offers glass wool, rock wool, foam glass, polystyrene foam, cellulose fibre and urea formaldehyde foam. The main data sources are environmental reports, LCAs (Richter et al. 1995, Althaus & Richter 2001) and encyclopaedic information.

Gypsum products: This chain is shown in the case study (chapter 4).

Plaster and Mortar: Nine different types of mortar and plasters are inventoried. Material inputs are taken from Kasser & Pöll (1998), other information is estimated.

Fibre cement products: The data for the three different fibre cement products (roof slates, corrugated slabs and facing tiles) is mainly based on a product declaration. Since the declaration isn't comprehensive, many assumptions were necessary.

Infrastructure and building material related processes: Different machines (hydraulic digger, rock crusher, power saw, conveyor belt and a general building machine) and generic buildings are inventoried manly based on rough estimates to be used as infrastructure processes. Data on the operation of the machines stem from BUWAL (2000) and they are more reliable. Also rough data on explosives and blasting is available.

Other important materials are inventoried in different contexts within ecoinvent and not further discussed here:

Iron, steel, aluminium and other metals: In most cases separate datasets are given for primary and secondary products as well as for the production mix in the year 2000, thus allowing the user to model material recycling potential in the way best suited for the goal and scope of his/her LCA. For more details see (Althaus & Classen 2004, Althaus et al. 2004).

Wooden products: Since forestry processes and processing commonly yield products of very diverse values (e.g. planned board and residue wood used as fuel), special attention has been paid to allocation. For more details see Hischier et al. (2004) and Werner et al. (2003).

Plastics: Mainly APME[1] data is used. These datasets are only available in cumulated form. Thus, among other inconsistencies, it was impossible to include the use of infrastructure. Most plastics are therefore not fully consistent with the rest of the ecoinvent data. (Hischier et al. 2004, Hischier 2004).

2 Modelling Principles

2.1 Data structure and boundaries

Ecoinvent Data v1.1 contains inventory data for many technically important building materials and related auxiliary products and processes. According to the general rules (Frischknecht et al. 2004a), the building materials are as far as possible inventoried in disaggregated unit processes. Some of these unit processes only have auxiliary character. Most products are offered with appropriate packaging material and process.

A major challenge of this project was to achieve consistent building material data using many different sources of very different comprehensiveness and quality. In order to do so, no general exclusion of missing data was applied, but estimations for missing data were made based on data for similar processes. In cases where the estimations result in relevant contributions to the environmental impacts, further research to strengthen the assumptions was either undertaken or is planned. For example, the dust emission from mining processes which results in relevant contributions to different materials will be further investigated.

Beside different metals (Althaus & Classen 2004), some building materials included in the database are produced using secondary materials from other processes (e.g. cellulose fibre (for insulation), gypsum fibre board and clinker). Since secondary material inputs do not bear environmental burdens of primary resource extraction, refining and manufacturing, but only those caused by collection, purification and / or processing (i.e. cut off approach is applied in the ecoinvent methodology (Frischknecht et al. 2004c), the demand of them as fuel or raw material in the clinker production does not show up as unit process exchanges. Thus, the mass, the biogenic carbon and energy flows of such datasets are not balanced. The use of secondary materials, however, is reported in the meta information related to the dataset.

2.2 Inventorying infrastructure and land use

1. Why should infrastructure be included?
There are different definitions as to what should be considered as infrastructure. Definitions of infrastructure in lexica and dictionaries range from 'the foundation or underlying framework of basic services, facilities and institutions upon which the growth and development of an area, community or a system depend' to 'the basic facilities, equipment, and installations needed to provide the utility products and services crucial for the growth and functioning of an economy, community or organization' (explicitly including 'the safety and control engineering systems (not only hardware devices,

[1] The Association of Plastic Manufacturers in Europe: <http://www.apme.org>

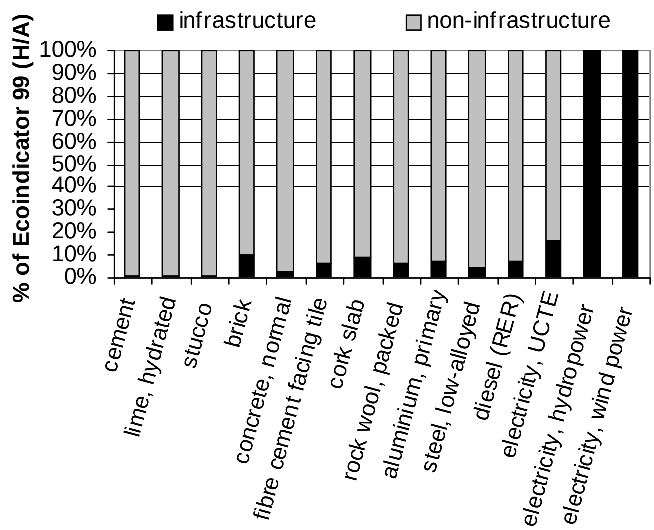

Fig. 1: Share of eco-indicator 99 (H/A) points resulting from infrastructure and non-infrastructure processes

but including operational procedures, organization and management) needed to make the system function according to its functional specifications')[2]. It is a question of debate whether, for example, an extruder to manufacture plastic tubes would be considered infrastructure according to these definitions. The electricity network on the other hand would clearly be considered infrastructure. Depending on the definition, the environmental impacts for some processes are caused exclusively by the infrastructure involved. Examples are hydro, wind and solar power. For material production, on the other hand, infrastructure usually is responsible for almost none to about 10% of the environmental burdens. Thus, the consistency of all data in a generic database in every possible context is only given if infrastructure is included in the inventories. **Fig. 1** shows that the exclusion of infrastructure in ecoinvent would be a cut-off which would not be based on environmental relevance. Since it would neither be based on mass or energy, it would not be in line with ISO 14041.

2. Rules for Inventorying Infrastructure in ecoinvent

For the reasons given above, the ecoinvent team decided to consequently include infrastructure. To ensure that infrastructure in ecoinvent is inventoried as consistently as possible, the group of administrators decided on a common set of rules:

Technical production facilities such as factories, machines, roads, cars, electricity transmission networks, etc. are regarded as infrastructure. Natural means of production such as mineral extraction sites, forests or agricultural land are not considered infrastructure. This definition is still problematic in a system of life cycle unit processes because it depends on the point of view as to whether or not a dataset is to be considered as 'production facility' or as product. Drilling of a well for exploration and production of oil, on the one hand, is a process needing, e.g. with a drill as infrastructure. On the other hand, the well itself is the infrastructure for the winning of oil. In these cases the point of view of the final intention of an ecoinvent dataset is taken. In the example, the drilling of the well is regarded as infrastructure because it is intended to be used only in this context and not to analyse the process of drilling.

Generally, infrastructure is inventoried as whole units (e.g. one complete power plant). Thus, the amount of infrastructure needed for a unit process is the inverse of the plants lifetime production. The output of the mine shown in Fig. 2 is 380'000 tons of gypsum per year. The mine is operated for 50 years. The life-time output is thus 19 million tons. The mining of 1 kg gypsum thus needs one 19'000 millionth (=5.26E-11) of a mine unit. Scalable infrastructure datasets for multi-storey buildings (m^3 building volume), fabrication halls (m^2 ground area), unspecific machinery (kg), electricity transmission networks (km), roads (km), etc., for example, are not inventoried as whole units.

At least the land use of the infrastructure has to be inventoried for every dataset in ecoinvent, since land use was expected to be of high relevance and land is occupied by infrastructure for most processes. Only the APME data on plastics, which do not include infrastructure, do not include land use[3]. For the other datasets, land use values are estimated if no information is available. The way of inventorying land use was developed based on the results of the 14th discussion forum at ETHZ in 2001[4], where experts discussed what information is relevant for the impact assessment step. Since transformation and occupation of land has to be assessed differently, these two processes are inventoried with separate exchanges. The occupation is expressed as the area

[2] Summary of definitions from <http://www.infrastructures.tudelft.nl/infradef.html> (23.06.2004)

[3] Since APME data is vertically aggregated and no information is provided about the up-chain processes, it is not possible to add infrastructure consistently to these datasets. It is expected for plastics production that the impacts of the infrastructure would be rather small compared to the other impacts.

[4] <http://www.texma.org/LCA-Forum/Documentation/documentation.html>

Flowchart			elementary flow in ecoinvent	amount	unit	source
land occupation for paved roads	→	Infrastructure limestone mine	occupation, traffic area, road network	20000	m2a	assumption from air-picture
land occupation for buildings	→		occupation, industrial area, built up	29000	m2a	
land use for buildings	→		transformation, to industrial area, built up	580	m2	
land use for buildings and paved roads	→		transformation, from forest	980	m2	
land use for paved roads	→		transformation, to traffic area, road network	400	m2	
building multi-storey	→		building, multi-storey	480	m3	
building hall	→		building, hall	500	m2	
		→ limestone mine	mine, limestone	1	unit	

Fig. 2: Example of infrastructure process for a limestone mine (used as proxy for gypsum mine) producing 380'000 t/year for 50 years

occupied for a certain time in the unit m^2a, while transformation indicates the area for which the type of land use is changed in m^2. The land use classes (e.g. urban area, meadow, forest, etc.) are derived from the CORINE[5] classes. Since a transformation is basically possible between different occupation types, the 'transformation to' and the 'transformation from' are treated as separate elementary flows to reduce exchange entries. More details on land use are found in Frischknecht et al. (2004b). **Fig. 2** gives an example of how land use is inventoried in an infrastructure process. The mine infrastructure occupies 980 m^2. This area is transformed from forest and transformed to industrial area and traffic area. If an active recultivation of this area will take place, a transformation from industrial area and to forest, for example, is inventoried in a separate dataset for the recultivation process. Since the 980 m^2 are occupied for 50 years, an occupation as industrial area of 49'000 m^2a is inventoried.

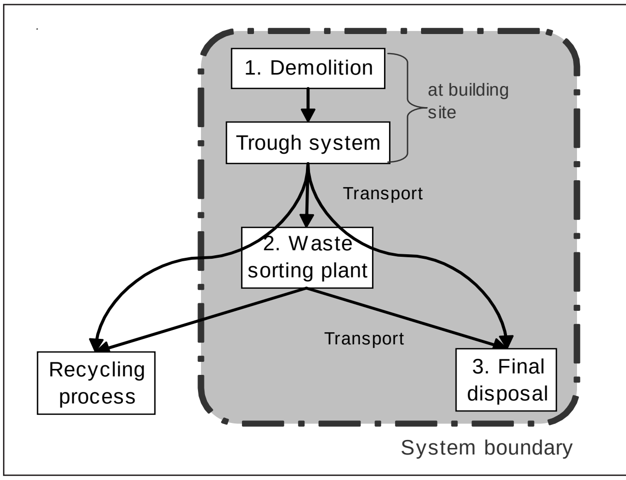

Fig. 3: System boundaries for disposal options of building materials

2.3 Waste disposal of building materials

To allow the user, construction-specific inventorying of disposal, several possible disposal options per material are inventoried. The three disposal options are A) direct recycling, B) recycling after sorting, and C) direct final disposal without recycling. The system boundary in the inventory includes expenditures on the building site, like demolition energies, for instance, but also transports, expenditures in a sorting plant and the final disposal of not recycled fractions in an incinerator or landfill. For the latter, the ecoinvent disposal models (parts II and III of Doka 2003) are applied, which give material-specific inventories of disposal processes. Depending on local circumstances at the building site, waste materials are sorted into several metal troughs or different materials are mixed in the same container.

In the ecoinvent methodology, no bonus or burden substitution is given for recycled material in these inventories. Also, no partial allocation of burdens from recycling processes to the old and the new products were made. Instead, the system boundary cuts off the recycling process itself, but fully includes sorting plants and disposal of non-recycled materials. Wastes with high recyclable content are thus relieved from the burden of disposal.

The disposal option 'direct recycling' (A) inventories only the burdens from dismantling (demolition energies and particle emissions; Box 1 in **Fig. 3**). The disposal option 'sorting plant' (B) includes dismantling, the sorting plant process and the final disposal of non-recycled fractions (Boxes 1, 2 and 3 in Fig. 3). The disposal option 'disposal without recycling' (C) includes dismantling and the final disposal of all waste materials (Boxes 1 and 3 in Fig. 3). The recycling process itself is not considered here (cf. Fig. 3) but must be heeded in secondary material production. For mixed building waste, the sorting process in option (B) is not considered a recycling process, but a necessary disposal process, since it must be sorted by law and cannot be disposed directly. Since recyclable fractions are generated in sorting and sorting can thus be viewed as a preliminary step prior to recycling, this procedure is consistent with the cut off approach generally used in ecoinvent.

As explained above, various fates for the construction materials are possible, depending on construction details and local circumstances. For example, gypsum plaster board, solid wood, brick, cement fibre slabs, rock wool and cellulose fibre insulation could be directly recycled if separated on site. Mortars and plaster are currently not recycled. Concrete can be recycled for its gravel content and reinforcement steel in a sorting plant, as well as bricks. Burnable materials, when not recycled, are assumed to be incinerated. If neither recycling nor sorting occurs, mineral materials can be landfilled

[5] <http://reports.eea.eu.int/COR0-part1/en>

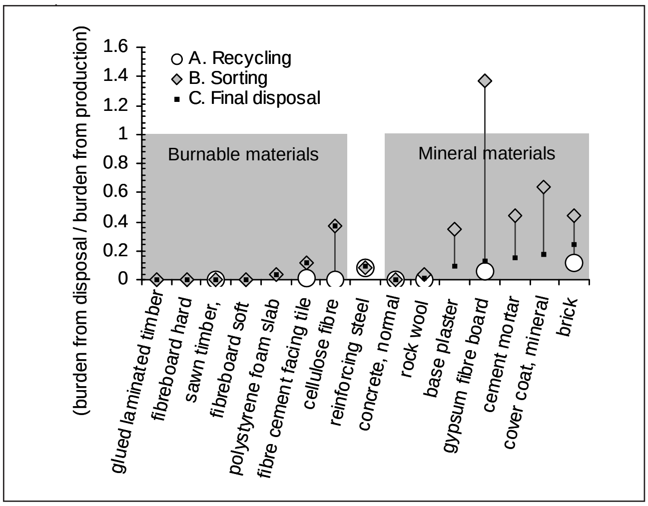

Fig. 4: Comparison of burdens from disposal options for some building materials with the burdens from production with Eco-indicator 99 (H,A). A value of 0.1, for example, means that the burdens from disposal are 10% as large as the burdens from production. If the sorting (B) scores higher than the final disposal (C), this is usually due to the disposal of fine fractions from sorting in a reactive sanitary landfill, while direct disposal would be in an inert material landfill

in an inert material landfill. However, the prerequisite for this is the waste separation on the demolition site.

Recycling, where possible, leads to the lowest burdens. Direct final disposal usually has an intermediate rank and the option 'sorting' generally displays the largest burdens[6]. With the sorting option, a part of the material is recycled, not creating any further burdens within the system. The other part is landfilled as fine fraction from the sorting plant. Due to the entire pollutant load in fine fractions, they cannot be landfilled in an inert material landfill, but are usually landfilled in a sanitary landfill. In ecoinvent emissions from a reactive sanitary landfill are modelled in detail for each waste fraction. For the inactive inert material landfills, however, no landfill emissions are inventoried yet, since they are considered of minor importance. Therefore, disposing a material *as a fine fraction* in a reactive sanitary landfill will result in much higher inventoried emissions than the disposal of the same material *as bulk* in an inactive inert material landfill. This is reasonable, as the chemical processes in the two landfill types are quite different indeed.

3. Relevance of building material disposal

A pragmatic way to discuss the burdens from disposal of materials is to compare it to the burdens from production. The ratio between the former and the latter is displayed in **Fig. 4** for burdens of different building materials expressed with Eco-indicator 99 (H,A). The larger the figures the larger the assessment mistake would be if the disposal phase of a material's life cycle were neglected. All three disposal options (direct recycling, sorting, and direct final disposal) are shown as appropriate, e.g. recycling of plasters and cement is not feasible. For burnable materials (at the left), disposal is usually of minor importance and the production phase is the dominant burden. For cellulose fibre insulation, however, the final disposal which is approximated by incineration of untreated paper is 40% of the burden from production. This is due to the fact that cellulose fibre is produced from recycled paper which, as a recycled product, carries no burden or benefits from the former product (cut off approach) in ecoinvent. Thus, the CO_2 uptake from air is not allocated to the waste paper, but the CO_2 emission from its incineration is. To avoid this effect, a similar methodological approach could be applied as that which is used for the modelling of the wood chain in ecoinvent (Hischier 2004, Werner et al. 2003). In this approach, an allocation correction would be defined to attribute the CO_2 uptake from air, the mass and the energy content of the old product to the recycling material. For mineral materials (at the right of Fig. 4), especially plasters and cement, the final disposal is 10% to 20% of the burden from production. The final disposal option for these materials is direct landfilling in an inert material landfill.

In conclusion, the disposal phase of building materials cannot generally be considered a negligible contribution to the life cycle. Since burdens from disposal are not energy related, CED is no suitable impact assessment method for the life cycle of building materials. For a comprehensive assessment, disposal must be included.

3 Case Study: Gypsum Fibre Board Production and Disposal

Gypsum fibre board is chosen as an example to discuss how building materials are inventoried. Gypsum fibre board consists of gypsum with 15–20% cellulose fibres. It has a density of 1000–1250 kg/m^3 and a thermal conductivity of 0.36 W/mK. Gypsum boards have good sound-absorbing properties and, because of the constitutional water, they show a good fire resistance and are consequently often used where these properties are required.

3.1 Production of gypsum fibre board

For the production of gypsum fibre boards, the stucco is mixed with water, cellulose fibres and additives and evenly spread on the belt of a calender. The board is pressed and, when the gypsum is set, the edges are cut and the surplus water is removed by drying for about one hour in a kiln. Finally the boards are cut and packed. Additionally, gypsum board uses starch and small amounts of glass fibres, siloxanes and surfactants as additives.

Most LCI information is taken from Coutalides (1998). Since no data for the demand of gypsum is found, it was calculated from the yearly production, the yearly demand of ancillaries and the stoichiometric demand of water (1.5 mol H_2O / mol stucco) for the setting. Since the source indicates only the water and energy consumption for the production of

[6] In a substitution system where – unlike as in ecoinvent – benefits would be given for recycled material, the 'sorting' option might rank better than 'direct final disposal', but worse than 'direct recyling'. If used with care, e.g. regarding dangers of double counting, substitutions systems can be an appropriate solution especially in consequential LCA (cf. Werner 2002).

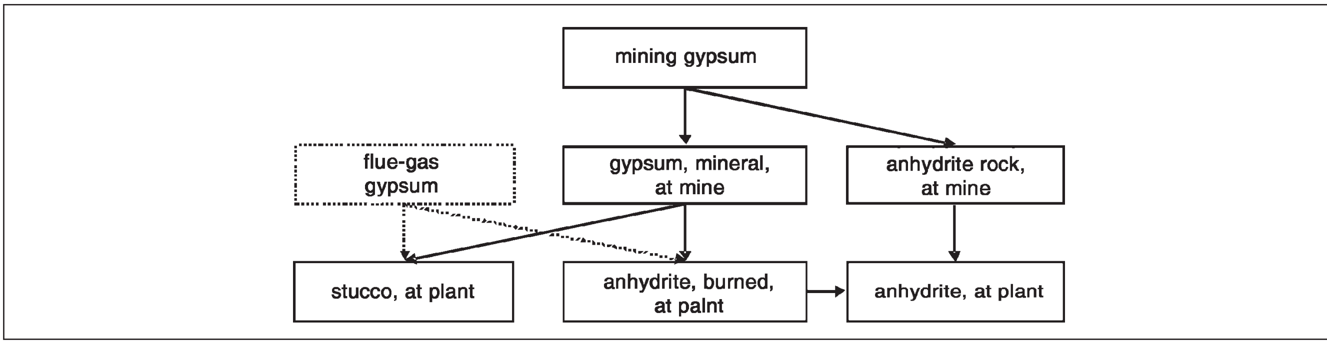

Fig. 5: Unit processes for the gypsum and the gypsum board production. Since 'flue-gas gypsum' is a by-product of other processes that is not used in Switzerland, it is not included in the database

solid gypsum board, these values are used to calculate the values for the other types of gypsum board assuming a linear relation of the water consumption and of the energy needed for drying to the amount of gypsum input. The amount of waste paper fibres in the gypsum fibre board is taken from Starzner & Wurmer-Weiss (2000). Gypsum fibre boards for the Swiss market are transported 300 km by lorry.

The production of stucco, the main input material, is shown in **Fig. 5**. In Switzerland, all gypsum is gained from open pit mines by blasting and digging. The gypsum layers are about 30–40 m thick. The intermediate products are composed of about 65% natural gypsum ($CaSO_4 \cdot 2\ H_2O$) and 34% natural anhydrite rock ($CaSO_4$), which are crushed and sorted, and 1% soil and gravel that is deposited back in the mine[7]. The mining process is inventoried as a multi-output process for gypsum and anhydrite. Mass allocation is applied. Stucco ($CaSO_4 \cdot 1/2\ H_2O$) is made by calcinations at 120–180°C from gypsum. In Switzerland, almost no flue gas desulphurisation gypsum is produced or used. In other European countries, the share of flue gas desulphurisation (FGD) gypsum production is considerable, e.g. in Germany where it is estimated to about 50%. FGD gypsum is produced by the desulphurisation of flue gas from fossil fuel incinerations. Since it is only produced to fulfil legal constraints on SO_2 emissions, it is regarded as a by-product and none of the burdens of the incineration process would be allocated to it in the ecoinvent methodology. Thus, for the European situation, where flue gas gypsum is used, the corresponding amount of natural gypsum could be replaced by this burden free input.

Results and discussion. Results are shown using the aggregated indicators eco-indicator 99 (H,A) and ecological scarcity 1997 and the cumulative energy demand (CED), since it is a common indicator for building products. Additionally, the human toxicity potential according to CML 2001 is chosen, because the aggregated methods imply a high relevance of PM_{10} emissions from mining. The results are shown in **Fig. 6**. The CED is dominated by the energy consumed for the calcination of the gypsum and the drying of the boards. The mining almost does not contribute. The transport of the fibreboard contributes about 20% to the fossil CED. The contribution of the transport is high in all the methods considered. The eco-indicator 99 and ecological scarcity indicator show high contributions of the dust emission from mining. However, the relatively small contribution of this emission to the human toxicity potential according to CML 2001 indicates that these two methods value

[7] Personal communication Mr. Buchheim, RiGips AG, 23.01.2002

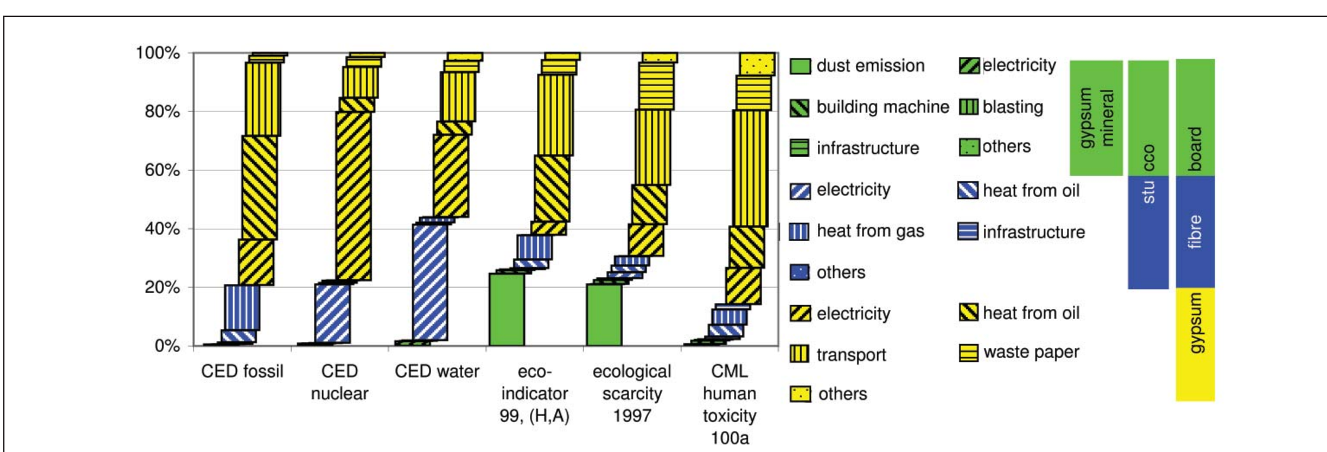

Fig. 6: Contributions to the LCIA results for gypsum fibre board. The contribution of the gypsum mineral extraction is shown in blue, blue and green together represent the contributions of the stucco production

PM10 emission rather high, especially compared to the heavy metal emissions from steel production, which contribute significantly to the high human toxicity potential of transport.

3.2 Disposal phase

Gypsum is a remarkable example for the difference of the direct disposal in an inert material landfill and the disposal of the fine fraction in a reactive sanitary landfill. Gypsum ($CaSO_4 \cdot 2H_2O$) is a harmless, inactive mineral with exceptionally good indoor climate characteristics. It can be disposed without risk in inert material landfills. There, it will dissolve to calcium ions and sulphate ions, both with little environmental risk. When gypsum is disposed in a reactive sanitary landfill as part of a sorting fine fraction, different processes occur. The dissolved sulphate (SO_4^{2-}) will be metabolised by the anaerobic microbes in the landfill and converted to sulphide (S^{2-}). Sulphide is mainly precipitated with iron ions (FeS) or it can be transferred to the landfill gas as gaseous dihydrogen sulphide (H_2S). In the latter case, the H_2S is oxidised to sulphur dioxide SO_2 either by incineration or flaring of the landfill gas or by atmospheric oxidation. Sulphur dioxide is a serious pollutant which contributes to acidification and secondary particle formation (winter smog). The formation and emission of H_2S in landfills from gypsum has been widely reported (e.g. Fairweather & Barlaz 1998, Johnson 1986). So, while direct final disposal of gypsum in an inert material landfill is hardly burdensome at all, the disposal via sorting plant (where it cannot be recycled) and fine fraction will create entirely different burdens. The sanitary landfill models in ecoinvent consider the composition of waste materials, the waste-specific degradability, reprecipitation of degraded or dissolved material, landfill gas formation and incineration. According to this model only a fraction of 6.5% of the sulphur in gypsum is converted to airborne sulphur dioxide. Due to the large sulphur content in gypsum, this burden is large enough to dominate the life cycle of gypsum product *for the disposal option via sorting plant only*. The disposal options 'direct recycling' and 'direct final disposal' have much lower burdens ranging at about 10% of the burden of gypsum production (see Fig. 4).

4 Conclusion, Recommendation and Perspective

Data on building materials in ecoinvent data v1.1 are generally of rather high quality. However, since data are generic and the building material industry is very diverse, uncertainties are considerable. For comparative assessments, data have to be used with care. In future versions, this situation could be ameliorated by including data for more specific product groups or even specific products. Another future improvement could be the inclusion of recycled building materials. ecoinvent v1.1 contains data for recycled metals, but not for other recycled building materials as e.g. concrete. Since reducing building waste by recycling is an issue for sustainable constructions, data should be added.

Disposal has to be carefully considered. Waste disposal, especially of mineral materials, can contribute considerably to the LCA of building materials and different disposal options can have very different environmental impacts. Since CED doesn't show these differences, it is not a suitable impact assessment method for the life cycle of building materials, especially if disposal is included.

Even if the contribution of infrastructure to the burdens of most building materials is rather low, neglecting it in a generic database would not comply with ISO 14'041.

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Ambiguities in Decision-Oriented Life Cycle Inventories
The Role of Mental Models

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Abstract. If the complexity of real, socio-economic systems is acknowledged, life cycle inventory analysis (LCI) in life cycle assessment (LCA) cannot be considered as unambiguous, objective, and as an exclusively data and science based attribution of material and energy flows to a product. The paper thus suggests a set of criteria for LCI derived from different scientific disciplines, practice of product design and modelling characteristics of LCI and LCA. A product system with its respective LCI supporting the process of effective and efficient decision-making should ideally be: a) complete, operational, decomposable, non-redundant, minimal, and comparable; b) efficient, i.e., as simple, manageable, transparent, cheap, quick, but still as 'adequate' as possible under a functionalistic perspective which takes given economic constraints, material and market characteristics, and the goal and scope of the study into account; c) actor-based when reflecting the decision-makers' action space, risk-level, values, and knowledge (i.e. mental model) in view of the management rules of sustainable development; d) as site- and case-specific as possible, i.e. uses as much site-specific information as possible. This rationale stresses the significance of considering both (i) material and energy flows within the technosphere with regard to the sustainable management rules; (ii) environmental consequences of the environmental interventions on ecosphere. Further, the marginal cost of collecting and computing more and better information about environmental impacts must not exceed the marginal benefits of information for the natural environment. The ratio of environmental benefits to the economic cost of the tool must be efficient compared to other investment options. As a conclusion, in comparative LCAs, the application of equal allocation procedures does not lead to LCA-results on which products made from different materials can be compared in an adequate way. Each product and material must be modelled according to its specific material and market characteristics as well as to its particular management rules for their sustainable use. A generic LCA-methodology including preferences on methodological options is not definable.

Keywords: Allocation; attribution; decision theory; inventory analysis; life cycle inventory (LCI); mental model; product system; subjectivity; valuesphere